Physical Modeling for Processing Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS) Hyperspectral Data

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Award Number: N000140110850
Grant Number: 144KE70
http://www.ssec.wisc.edu/gifts/navy/

LONG-TERM GOALS

This Office of Naval Research (ONR), Department of Defense (DoD) research effort has three main long-term goals. They are: 1) to bridge the physical principles of a hyperspectral data retrieval problem with the mathematical algorithms that try to solve it; 2) mathematically quantify the location of useful information to complete a physically-driven application in the electromagnetic spectrum, and 3) develop physically-based hyperspectral data processing applications for surface material identification, atmospheric parameter retrieval formulation, and coastal water quality assessment.

OBJECTIVES

The objective of this DoD research effort is to develop and demonstrate a fully functional GIFTS hyperspectral data processing system with the potential for a transition to operational deployment in a centralized and/or shipboard real-time processing environment once GIFTS is stationed over the Indian Ocean. The system will provide specialized methods for the characterization of the atmospheric and surface material components of the battlefield environment that will take good advantage of the revolutionary capabilities of the new GIFTS mission.

APPROACH

This project involves four research objectives of this DoD ONR Multidisciplinary Research Program of the University Research Initiative (MURI) initiative. The plan charts an evolution of GIFTS, from information content, to describing mesoscale (length scales 25−1000 km) environments.

1. *Mathematical Quantification of Useful Hyperspectral Information.* UW Co-Investigators (Co-I) Dr. Jun Li, Dr. Bormin Huang, Dr. Paul Lucey, Erik Olsen, and PI Dr. Allen Huang to develop methods that objectively identify the information-rich radiance channels that possess the most useful information.

2. *Radiative Transfer Modeling* (*Clear and Cloudy-Sky Emission/Absorption, Atmospheric Particulate Emission/Absorption, Surface Emission/Absorption*). Drs. Dave Tobin, Leslie Moy Allen Huang and Jim Davies have produced an improved clear-and cloudy-sky fast radiative transfer model

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2003**	2. REPORT TYPE	3. DATES COVERED **00-00-2003 to 00-00-2003**

4. TITLE AND SUBTITLE
Physical Modeling for Processing Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS) Hyperspectral Data

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Cooperative Institute for Meteorological Satellite Studies (CIMSS),,Space Science and Engineering Center (SSEC),,University of Wisconsin-Madison (UW),1225 West Dayton Street,Madison,,WI,53706

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

for GIFTS. This involves subcontractors Dr. Ping Yang (Texas A&M Univ.), and Drs. Gary Jedlovec and Sundar Christopher (Univ. of Alabama-Huntsville).

3. *Mathematical Retrieval Algorithm Development* (*Atmospheric Parameters, Suspended Particulate Detection and Quantification, Sea Surface Temperature, Surface Material Identification*). Co-I's Dr. Steve Ackerman, Dr. Allen, Dr. Jun Li, Dr. Paul Lucey (UH), Wayne Feltz, Chris Velden, Dr. Irina Sokolik, (Univ. of Colorado–Boulder) and Dr. John Mecikalski are developing parameter retrieval methods.

4. *Product Research* (*Ocean Surface Characterization, Lower Tropospheric Temperature, Moisture and Winds, Surface Material Products, Aerosols, Derived, Second Order Products*). Co-I's Dr. John Mecikalski, Dr. Paul Lucey, Chris Velden, Wayne Feltz, Derek Posselt, and Dr. Steve Ackerman are using simulated GIFTS data within retrieval algorithms.

WORK COMPLETED

Funding over the period 1 October 2002–30 September 2003 through this MURI Topic #15: *"Physical Modeling for Processing of Hyperspectral Data"* has been used to perform basic research in the above four research areas. This research has involved UW CIMSS investigators, as well as four subcontractors outside UW. The main reporting activity occurred on 28-29 May 2003 through the *Third MURI Workshop* at the UW CIMSS. This workshop brought together the DoD MURI program managers, ONR science advisors, NASA, NOAA and Naval Research Laboratory representatives, UW MURI subcontracted investigators [from the University of Alabama–Huntsville (UAH), Texas A&M University (TAMU), and the University of Colorado at Boulder (UCB)] and UW and University of Hawaii (UH) MURI investigators. During this two-day meeting, all non-MURI representatives were informed of progress made in the area of hyperspectral GIFTS data simulation and retrieval algorithm development. In addition, the UW PI, Program Manager (PM), and all Co-I's obtained a more complete understanding of this MURI program.

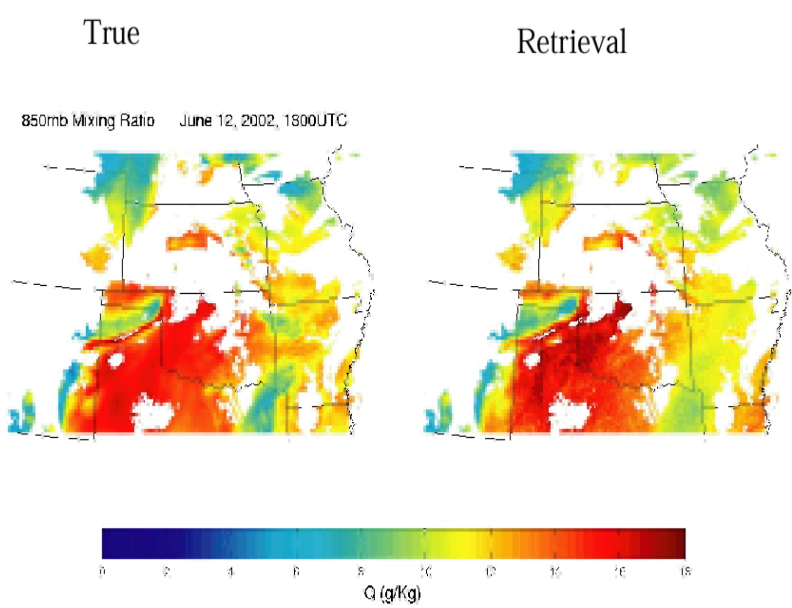

Figure 1. Truth versus retrieved 850 mb mixing ratios. The "truth" data are taken from simulated GIFS data using the MM5 model.

A main focus of UW-MURI's third funding year has been to use simulated hyperspectral data for 1) GIFTS "fast" model development, 2) GIFTS clear- and cloudy-sky "forward" radiative transfer (RTE) model development, and 3) GIFTS "retrieval" algorithm development. The simulated GIFTS data are considered "truth" to which any subsequent algorithm test can be compared. Temperature and water vapor profiles, surface temperature, surface height, liquid water content, and ice water content are extracted from simulated data and used as input to a coefficient regression-based RTE model. The GIFTS RTE model produces interferogram information and top-of-the-atmosphere (TOA) radiance "cubes" of the quality expected from the GIFTS instrument [128 x 128 (4 km) array at 0.57 cm^{-1} spectral resolution; 776 radiance channels from wave numbers 685-1130 cm^{-1}; 1047 channels from 1650-2250 cm^{-1}]. From these spectra, atmospheric state variables are retrieved, and quality tested against the original model data they were generated from. Figure 1 shows simulated GIFTS 850 mb mixing ratios over the International H2O Project domain for 12 June 2002, and subsequent retrievals of this quantity. A final step in the GIFTS simulation procedure involves computing instrument-specific effects for radiance spectrum, including apodization, off-axis effects, detector responses, background contributions from the instrument, and quantization of the signal for conversion to a digital stream.

Both clear- and cloudy-sky forward RTE model developments for GIFTS retrievals have occurred. It involves: 1) Adding functionality to the existing GIFTS fast model, 2) Developing an improved fast "forward" RTE model, and 3) Developing a proper representation of clouds (ice and liquid water) particle concentrations, and associated RTE representations of clouds of various composition, into a "cloudy-sky" RTE model.

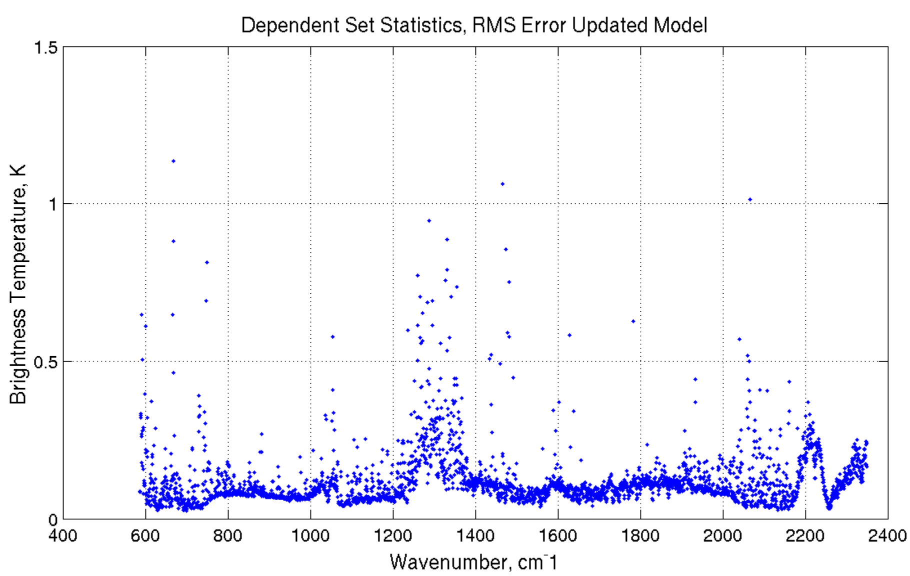

Figure 2. The dependent set statistics for both the existing model and the upgraded Clear Sky RTE model for GIFTS.

The GIFTS Clear Sky Forward Model was upgraded, resulting in improved accuracy statistics. A more stable regression method using single value decomposition analysis replaced ridge regressions that were subject to conditioning problems. Figure 2 shows plots of the dependent set statistics for both the upgraded model. The greatest improvements were in the water vapor regions where the conditioning

problems exist. Also, the optical depths were weighted so that biasing from very opaque profiles is reduced. Other improvements include formal software control and flexibility, improved predictor values, more current line-by-line calculations. An adjoint model for our forward model is complete and being tested; it will be useful for data assimilation. This is a "LBLRTM based PLOD-type" model. We are currently characterizing the accuracy of this model (within machine precision) with comparisons to profile from the Atmospheric Infrared Sounder (AIRS) instrument.

A new liquid cloud and ice cloud model has been incorporated into the GIFTS fast RTE model (GIFTSFRTE). This code can now rapidly simulate radiances for cloudy GIFTS FOVs for both liquid and ice (hexagonal crystal) clouds. Currently the code is limited to clouds of one layer and single phase. Enhancements include: 1) Addition of surface spectral emissivity (ε), 2) Simulation of multi-layer and mixed phase clouds with existing transmission and reflection look up tables, and 3) Expansion of the range of transmission and reflection look up tables for more ice crystal habits. Figure 3 demonstrates the comparison between GIFTSFRTE and LBLRTM/DISORT for liquid clouds.

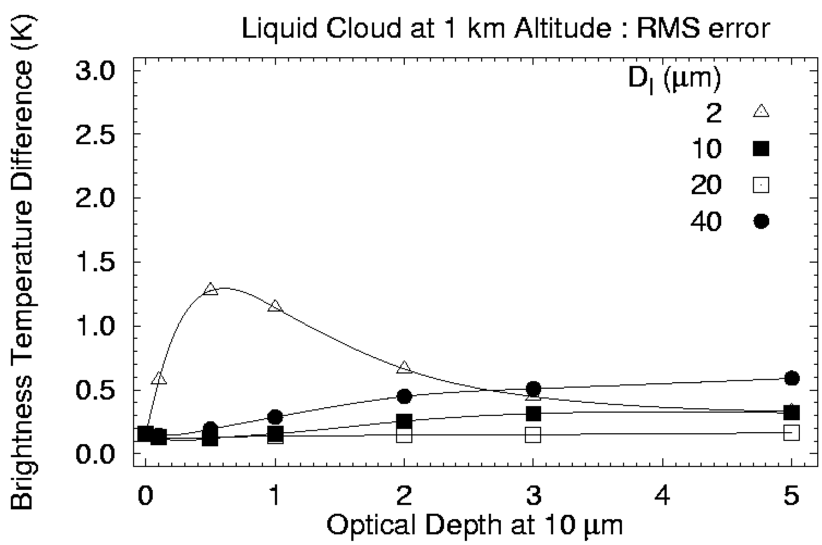

Figure 3. GIFTS LW band, RMS deviation between GIFTSFRTE and verification code (LBLRTM/DISORT) for liquid cloud, 1 km cloud top height.

A physical retrieval algorithm has been developed for temperature (*T*) and water vapor (*q*) soundings from GIFTS radiances. GIFTS radiances are calculated from radiosonde observations of the atmospheric state using the fast RTE model. GIFTS instrument noise is added, and a regression followed by a nonlinear physical retrieval procedure (Li et al. 2000; Zhou et al. 2003) is applied to the simulated GIFTS radiances for *T* and *q* profile retrievals. The retrieval algorithm has been improved for *T* and *q* sounding retrieval from GIFTS radiances through use of improved training data, more realistic surface ε assignment in the training, and improved use of the local zenith angle in regression retrieval. The algorithms were tested using EOS Aqua's MODIS and AIRS radiance measurements with improved *q* the result. Figure 4 shows the TPW retrieval images from MODIS radiance measurements with more physical realistic ε (lower panel) and artificial assigned ε (upper panel).

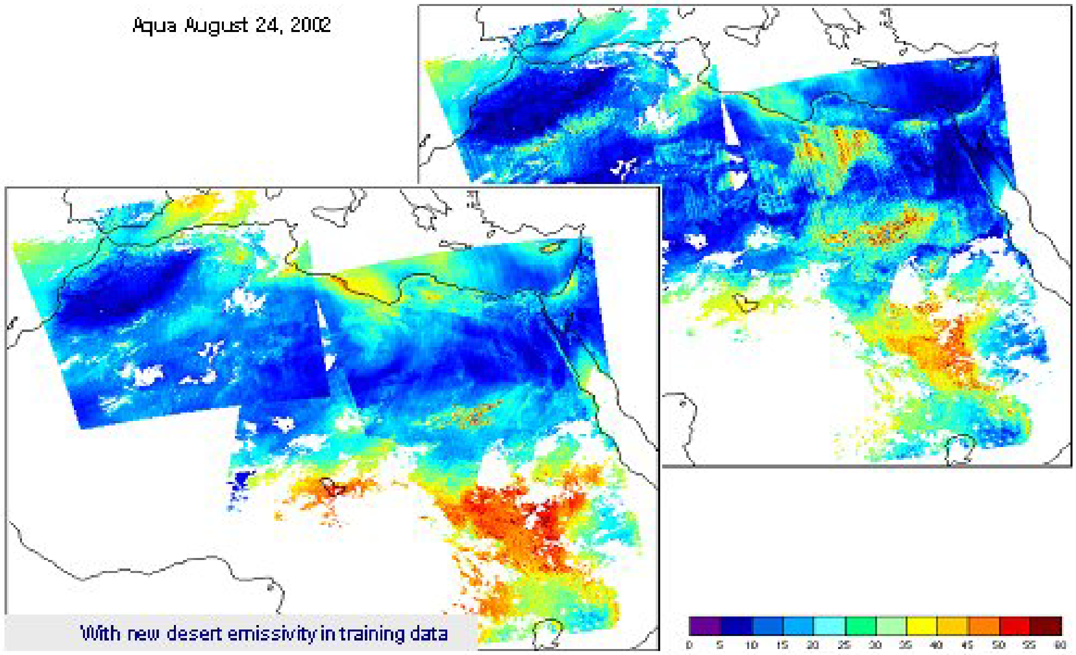

Figure 4. Total precipitable water (TPW) retrieval images from Aqua MODIS radiance measurements with new emissivity (more physical realistic) in training (lower left panel) and old emissivity (artificial assigned) in training (upper right panel) on 24 August 2002.

A recent study has shown that the CIMSS winds retrieval algorithm is model first-guess independent, providing the needed flexibility. Improvements are being made to improve performance to form sensor-independent code. One of the primary objectives of the MURI research is to determine if accurate wind profiles can be deduced in the marine environment from tracking moisture fields derived from hyperspectral soundings. A marine environment case was chosen during the THORPEX field campaign near Hawaii; simulated GIFTS data were used and winds were generated. It was determined that dew point temperature was the best moisture quantity for wind tracking purposes over three consecutive time intervals (30-minute intervals). This provides a benchmark on winds producability from forthcoming height-resolved moisture satellite analyses.

Atmospheric parameter regression retrievals from the GIFTS simulated data, for lifted index and equivalent potential temperature, show that differences ("truth–retrieved") are ±2.5 for lifted index, and ±3.5 for equivalent potential temperature. Additional work has been done to evaluate boundary layer turbulence and cloud growth using hyperspectral measurements (Mecikalski et al. 2003).

Ongoing research at UH involves 1) improving surface ε estimates from hyperspectral measurements, and 2) transitioning the UH longwave infrared (LWIR) Airborne Hyperspectral Imager (AHI) instrument to match the radiance spectra of the forthcoming GIFTS instrument. The UH has established a methodology for accurately estimate surface spectral ε using a combination of high-resolution spacecraft data and library information, the end result being a map of ε over large geographical areas. This work allows UW and UH to fully collaborate as UW is sharing simulated GIFTS data with UH, and UH provides improved ε algorithms to UW.

Other UW MURI subcontractor involvement is summarized as follows: UAH has developed algorithms suitable for processing GIFTS measurements to differentiate cloudy regions from clear and identifying unique characteristics such as cloud type, and height. Work by UCB will involve the detection of aerosol and dust, distinguishing these from water clouds in hyperspectral data. This UCB work requires the development of forward modeling capabilities to characterize spectral signature of dusts of different origin. UCB will analyze high spectral data collected during heavy dust conditions and develop appropriate model to interpolate and model its radiative effects. The TAMU continues to work heavily on cloud-sky radiative modeling, with emphasis on both ice and water clouds.

RESULTS

The meaningful technical results since from 1 October 2002—30 September 2003 are summarized:

- Full development of simulate GIFTS data; the creation of 7 GIFTS simulation data sets.
- Continued improvements to clear- and cloudy-sky RTE models at CIMSS and TAMU for GIFTS.
- A physical non-linear algorithm for the retrieval of atmospheric *T* and *q* profiles simultaneously from GIFTS radiance spectra. Estimates of surface ε using hyperspectral data at UH.
- Aerosol and dust modeling from UCB that uses GIFTS data sets.
- Development of various applications of hyperspectral data in the areas of clouds (UAH), turbulence and convection (CIMSS), and cloud properties (CIMSS).

IMPACT/APPLICATIONS

The immediate application and impact of the basic research accomplished to date is the use of simulated GIFTS-IOMI data to formulate atmospheric parameter retrieval algorithms to form the meteorological products highlighted by DoD as valuable to Navy fleet operations.

TRANSITIONS

The algorithms described above for GIFTS continue to development. No person or institutions outside UW and UH are utilizing them. The basic research is being performed to form robust atmospheric parameter products to address the Year 3-5 proposed tasks. In addition, UH continues to coordinate UW on basic surface characterization research as improved surface ε estimates are obtained. All UW subcontractors will collaborate toward completion of a full (clear-sky, cloudy-sky, surface) suite of retrieval algorithms. Student sharing between UW and UH is occurring.

RELATED PROJECTS

The projects that closely relate to the UW and UH MURI basic research initiative include: 1) the GIFTS development work at UW supported by NASA and NOAA, 2) student and basic research involvement with Prof. Morgan of UW for using GIFTS-IOMI for NWP, data assimilation and atmospheric parameter retrievals, and 3) the future value of this basic research to a number of UW CIMSS projects related to mesoscale nowcasting for aviation safety issues.

SUMMARY

To date, this UW and UH MURI has provided to the scientific community the first procedures for simulating and using hyperspectral radiance information from GIFTS-IOMI instrument to form atmospheric products that will describe the mesoscale battlespace. These products will some day enhance the efficiency of Naval activities by providing to fleet highly specialized meteorological information. The development of a first retrieval algorithm and a fast radiative transfer model for GIFTS-IOMI, the transitioning of the AHI instrument to GIFTS-IOMI spectral resolution, and the ability to simulate GIFTS data, highlight the progress that UW and UH have made to date.

REFERENCES

Huang, H-.L., P. Yang, H. Wei, B. A. Baum, Y. Hu, P. Antonelli, and S. A. Ackerman, 2003: Inference of ice cloud properties from high-spectral resolution infrared observations. Submitted to *IEEE Trans. Geoscience Remote Sens.*

Li, J., W. Wolf, W. P. Menzel, W. Zhang, H.-L. Huang, and T. H. Achtor, 2000: Global soundings of the atmosphere from ATOVS measurements: The algorithm and validation, *J. Appl. Meteorol*., **39**: 1248-1268.

Mecikalski, J. R., K. M. Bedka, D. D. Turner, and W. F. Feltz, 2003: The identification and quantification of waves and roll turbulent structures within the convective boundary layer from high-time resolution remote sensing data. Submitted to *J. Geophys. Res*.

Zhou, D. K., W. L. Smith, J. Li, H. B. Howell, G. W. Cantwell, A. M. Larar, R. O. Knuteson, D. C. Tobin, H. E. Revercomb, G. E. Bingham, J. J. Tsou, and S. A. Mango, 2003: Geophysical product retrieval methodology for NAST-I and validation, *Applied Optics* (in press).